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ScienceDirect
Procedia Social and Behavioral Sciences
Procedia - Social and Behavioral Sciences 195 (2015) 2370 – 2375

World Conference on Technology, Innovation and Entrepreneurship

Power Quality Measurement and Evaluation of a Wind Farm Connected to Distribution Grid

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Abstract

Wind power can bring new challenges when it is connected to the power grid. Generated power from wind energy system is always fluctuating due to the fluctuations in the wind. This paper shows a study on Power Quality (PQ) analysis of wind turbines installed in Hatay region and has been working for three years. Power quality parameters such as voltage, current, active, reactive and apparent power and harmonics are measured, analyzed and evaluated taking into consideration IEEE 519-1992 standards. These parameters are continuously measured for three months. The recorded parameters are voltage and current rms values of all single phase for every 10 power frequency cycles, average values of current and voltage harmonics every 3 sec, active, reactive, and apparent power values and the power factor every second.

Peer-review under responsibility of Istanbul Univeristy.

Keywords: Wind farm, power quality, Harmonic

1. Introduction

The negative effects of fossil fuels have forced researchers finding new and renewable energy sources that are both environmentally more suitable and renewable (Sankaran, 2002; Ertay and Duru, 2012; Alessandro, 2008; Stavros and Fritz, 2006) Wind energy is a renewable energy sources and has shown very fast development in the whole World. Wind energy, in special; have received huge interest by both private investors and governments. Integration of wind power into power systems presents many new challenges. Like conventional power plants, wind power plants must provide the power quality required to ensure the stability and reliability of the power system it is

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1877-0428
Peer-review under responsibility of Istanbul Univeristy.
doi:10.1016/j.sbspro.2015.06.211

connected to and to satisfy the customers connected to the same grid (Sekkeli, 2009; Sekkeli and Yilmaz, 2009; Sekkeli and Tarkan, 2013; Tascikaraoglu, 2011; Imal et al., 2012). Although many operational aspects affect wind power plant operation, this paper, focuses on power quality (Sankaran, 2002; Kusiak and Zheng, 2010). This narrower definition of power quality (PQ) allows to focus on supply waveform problems, its frequency and magnitude. Power quality has received a great deal of attention recently, since the increased use of power electronic devices which are non-linear loads drawing nonlinear currents from the power supply (Sankaran, 2002; Kocatepe et al., 2009). Although there are many parameters affecting on power quality, harmonics are one of the major power quality problems in power systems. Harmonic disturbances are a phenomenon associated with the distortion of the fundamental sine wave and are produced by nonlinearity of electrical equipment. Harmonics causes increased currents, power losses and possible destructive overheating in equipment (Sankaran, 2002; Mutlu et al., 2009). There are power quality standards that define the maximum allowable limit of distortion in voltage and current waveforms of the power supply. Many standards, guidelines and recommendations including IEEE standard 519-1992 and IEC 61000 series of standards have come into effect in this regard (Sankaran, 2002; Hocine and Mounira, 2011; Chen et al., 2009; IEEE Standard 519-1992, 1992). Also, some indices like Total Harmonic Distortion (THD) and Total Demand Distortion (TDD), used respectively for voltage and current harmonics (IEEE Standard 519-1992, 1992). In this study, an investigation is carried out to measure and evaluate the power quality in a wind farm installed at Hatay region.

2. Power Quality Indices Under Harmonic Distortion

Harmonic indices have been developed to assess the service quality of a power system with respect to the harmonic distortion levels. These indices are measures of the effective value of a waveform and can be applied to both the current and the voltage. The IEEE-519 document has set limits on the level of allowable harmonics (IEEE Standard 519-1992, 1992). Several indices are available for harmonic analysis; however, the two most commonly used are the total harmonic distortion (THD) and the total demand distortion (TDD). Mathematical formulations of (THD) and (TDD) for voltage and current are given in equations (1), (2) and (3) respectively:

$$THD_V = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \tag{1}$$

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \tag{2}$$

Where V_1 and I_1 are the RMS value of the fundamental, and Vh and Ih are the RMS value of the h-order harmonic component. Total Demand Distortion (TDD): Is the total harmonic cur-rent distortion defined by the ratio of the RMS value of the sum of the individual harmonic amplitudes to the maximum or rated demand load current IL as shown in the following expression:

$$TDD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_L} \tag{3}$$

3. Description Of Wind Farms

Belen wind farm is installed at Hatay province of Turkey in Mediterranean region. Wind farm has been installed with a total capacity of 36 MW and constituted by 12 wind turbine. Rotor diameters and hub heights of wind turbines are 90 m. and 80 m. respectively. The nominal power of each turbines are 3 MW manufactured by Vestas V90. So far wind farm has been effectively worked and produced electrical energy. The picture of wind farm derived from Google earth is shown Fig.1. In wind turbines of installed wind farm, three-phase wound rotor induction generator is used. Each wind turbine generator has been connected to its own 0.69/34.5 kV star-delta connected transformer. The neutral point of the transformer is grounded to diminish the third harmonic voltages. These generators are connected to 154 kV power lines via 154/ 34.5 kV, 50 MVA transformers. The substation also ensures that the electric power generated from wind is delivered to the transmission line at constant voltage level of 154 kV and 50 Hz.

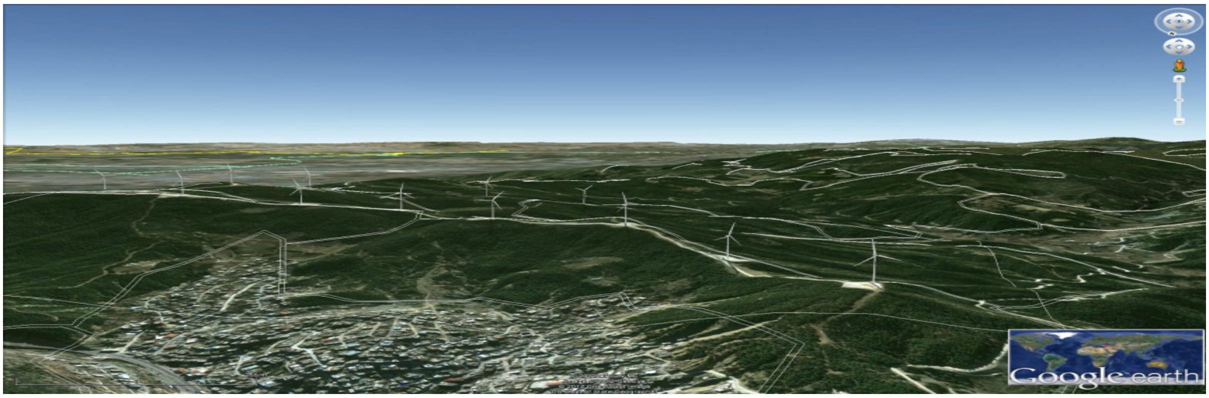
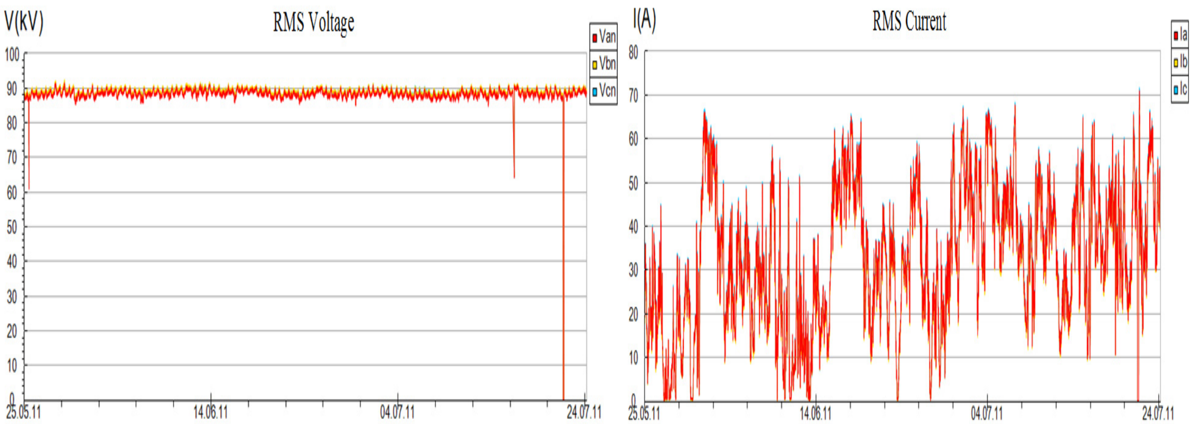


Figure 1. Picture of wind farm derived from Google Earth

4. Result and discussion

In this study, electrical parameters of wind farm such as voltage, current, frequency, active, reactive, apparent power, power factor and harmonic distortions are given and analysed as follows. These values are measured and obtained for the time periods of three months. The recorded parameters are voltage and current rms values of all signals phase for every 10 power frequency cycles, average values of current and voltage harmonics every 3 sec, active, reactive, and apparent power values and the power factor every second. Waveforms of the voltage and current measured from wind farm feeder while all wind tur-bines (12 wind turbines) were working are given in the Fig.2. Voltage measurement is performed at High voltage level of 154 kV substations for single phase-neutral. High voltage ranges in Turkey for three phases are 154 and 380 kV and single phase 90 and 220 kv 10% respectively. As seen from true-rms single phase voltage variation in 154 kV side in Fig.7, voltage level does not exceed the limit through measurement period. According to the Fig.6 although a slight ripple of voltage waveform, it is seen that nominal volt-age amplitudes are nearly constant at about 90 kV.



(a) (b)

Figure 2. Voltage-Current values and waveform of wind turbine output

Similarly, Waveform of the current are also very ripple depending on generated power at wand farm. Voltages and currents are illustrated as single phase. Waveforms of active, reactive and apparent power measured on wind farm feeder while all wind turbines were generating active power, are shown in Fig.3. These 12 turbines are identical and assumed to be running under same shaft torque. The power parameters have been measured and recorded at every 10 min on wind farm feeder.

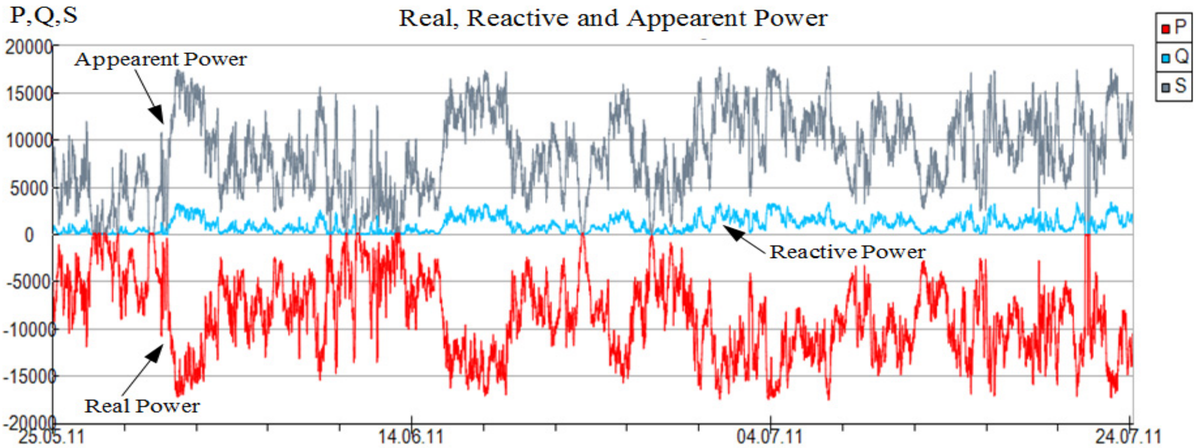


Figure 3. Waveforms of the active, reactive and apparent power measured at wind farm feeder

Measurement results show that the real power has been generated between 0 and 20 000 kW while the reactive power varies between 0 and 2500 kVAr. Changes in wind speed often result in wind turbine active and reactive power fluctuations. The output real power depends on the wind speed on wind energy conversion system. Reactive power compensation systems have been installed on the wind farm in order to minimize reactive power generated from wind turbines. Power factor values measured from the feeder after compensation are given in Fig.4. As shown in Fig.4, power factor are almost close to 1 value desired set point by means of the compensation system.

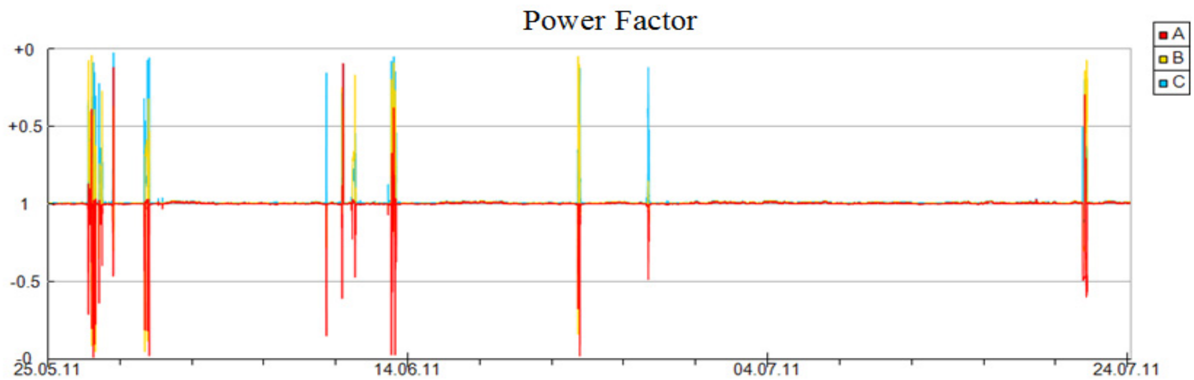


Figure 4. Power factor values measured on wind farm feeder

Output frequency at wind farm feeder is very important and it has to be constant at 50 Hz which is nominal value at Turkey distribution system. As seen on Fig.5, nominal frequency is constant at 50 Hz. Voltage and current harmonics are evaluated on wind farm. Measured total harmonic distortion (THD) of voltage and current in wind farm feeder is shown in Fig.6. These measured values show that the THD is usually less than the limit specified by IEEE Std. 519-1992 for industrial harmonics loads (IEEE Standard 519-1992, 1992). Voltage and current distortion limits are given in Table 1 and 2 according to IEEE Std. 519-1992 respectively. The power quality data from measurement are processed in accordance with IEEE 519-1992. As seen from Fig.6, in evaluation of voltage harmonics, THD of voltage for Wind Farm exceed the limits defined in IEEE 519-1992 in Table 1. In Table 2, standard limits are specified from acceptable current harmonic limits defined by IEEE 519-1992. By com-paring limit values in Table 2 to measured values, limit of total current distortion is not exceeded in Wind Farm as shown in Fig.6.

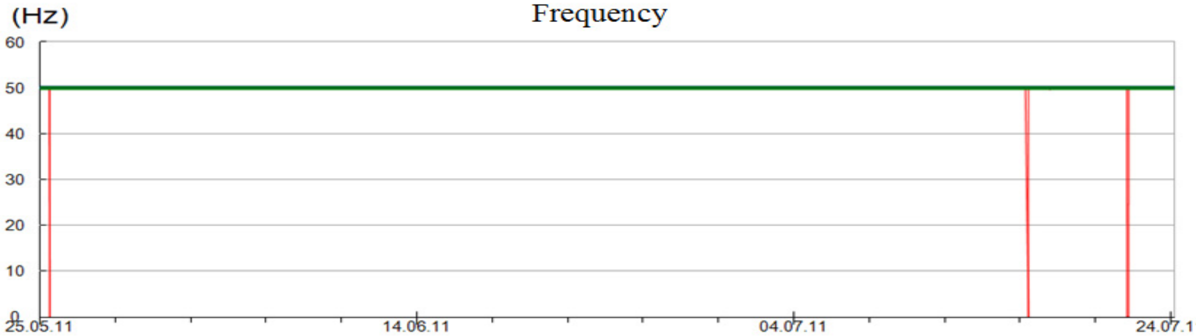


Figure 5. Nominal frequency values measured at wind farm feeder

Table I. Voltage Distortion Limits For General Distribution System

Voltage Distortion Limits		
Bus Voltage at PCC	**Individual Voltage Distortion THD (%)**	**Total Voltage Distortion THD (%)**
69 kV and below	3.0	5.0
69.001 kV through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5

Table II. Current Distortion Limits For General Distribution System At Medium And High Voltage

Current Distortion Limits for General Distribution Systems (120 V Through 69 kV)						
Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{sc}/I_l	<11	11<h<17	17<h<23	23<h<35	35<h	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

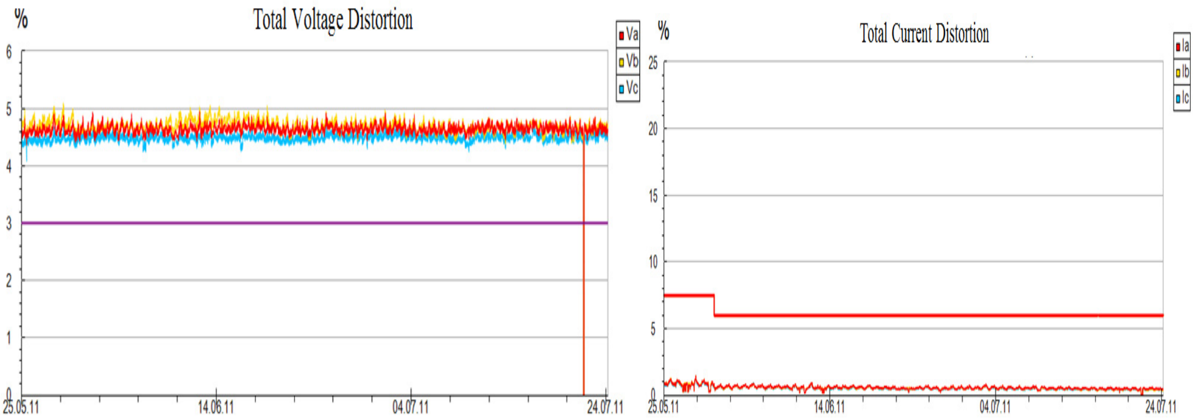


Figure 6. THD of Voltage and current for wind farm on output feeder for three phases

5. Conclusion

In this paper, the power quality issues of wind plants at the point of common coupling with the HV transmission network are investigated. Voltage, current, frequency, active, reactive and apparent power, power factor and harmonics have been analyzed and evaluated based on IEEE 519-1992. The investigation shows that the harmonic values of wind plants have a slightly negative impact on the medium level of transmission network while the other parameters are mainly good. This analysis on real measurements is performed on total output of wind farms having 12 turbines.

6. Acknowledgment

Authors would like to thanks BELEN Wind farm, it's own and manager and Wind Power Monitoring and Forecast Center (RITM) for their helps, collaboration and supports in our study.

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